Newsletter for July 2024

- Tail Project Update
- Volunteer Spotlight: Lathreas

Tail Project Update

By Bleddyn, Mecknavorz, Nalco, and Pepper
July 30, 2024

Haroo folks! Bleddyn here. The Tail Team has been hard at work, and we've reached milestone goals with our software and hardware development. In this article, we wanted to offer a look at how we reached those goals and what comes next.

We have been focused on improving our systems to measure electrical signals from muscle action in the body—a technique called electromyography (EMG). We plan to use these signals to intuitively control the motion of a prosthetic tail. However, measuring these signals was not as simple as it had seemed, and we've been working ever since to develop a useful measurement system. We needed our system to sample muscle signals at a rapid and steady rate, and we needed those signals to be free from interferences as the wearer moved. We also decided early on that we wanted a way to view the muscle signals in real time, which would help us to understand how our system was responding to muscle action.

Our latest series of newsletter updates (December 2023 for hardware, February 2024 for software) showcased progress towards these goals and the methods we were using to make that progress. Now, a few months later, we believe we have reached a point where our measurement system can be used to record meaningful EMG data.

Hardware
In our last hardware update, Nalco laid out the development process for our active EMG electrodes. These devices were intended to replace the passive electrodes that were a standard component of our off-the-shelf EMG amplifier, the MyoWare. We believed that the passive electrodes were responsible for the interference we had observed in our measurements (from wire motion and touching), and that the operational amplifiers built into each active electrode would eliminate this interference by reducing the impact of capacitive coupling to the electrode wires.

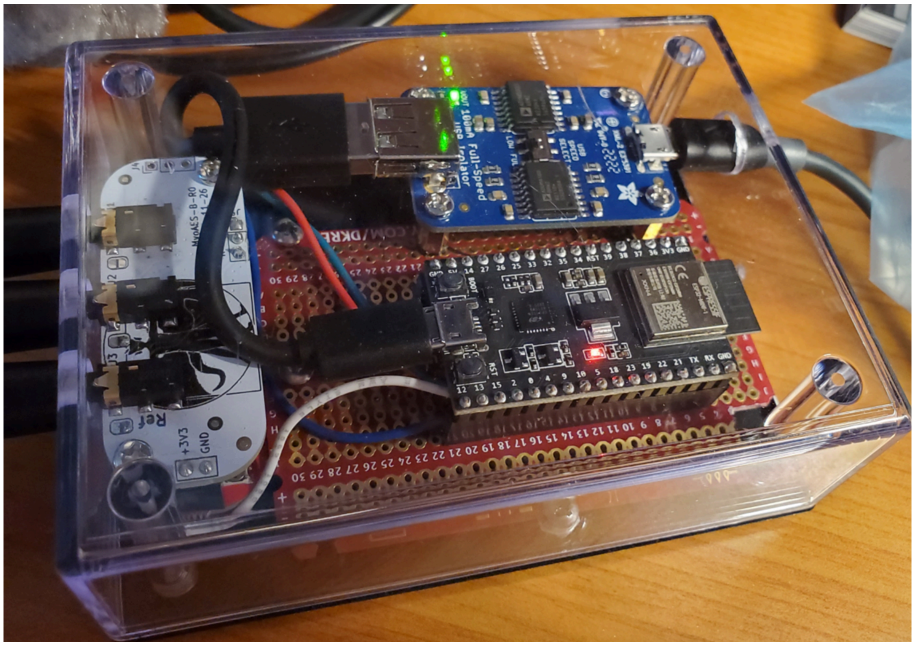
Fig. 1. Photograph of a completed prototype of the Tail Project EMG measurement system.

As a first order of business, Nalco packed up and shipped a set of active electrodes to each of Meck and myself. (He also shared some neat circuit boards from his protogen project. I later termed these Toaster Coasters™.) This shipment allowed us to corroborate each others' tests with the active electrodes and share the work of further troubleshooting.

Meck was busy with software development, but I was able to use these electrodes and our custom MyoWare Active Electrode Shield (MyoAES) to complete my assembly of a measurement system (Figure 1). This measurement system comprised a USB isolator, an ESP32 development board, and a MyoWare 1.0 with MyoAES in a polycarbonate enclosure. The MyoAES connected to two active electrodes and one passive electrode through three shielded TRRS cables, each providing power, ground, signal, and shield connections. This was satisfying to assemble because of its similarity to our original design for the improved measurement system.

Using this system, I was able to observe key performance differences between the active and passive electrodes. First, attaching passive electrodes to the shielded cables showed that these new cables were just as sensitive to motion and touching as the unshielded cables we had used previously. Switching to active electrodes, it was immediately clear that the active electrodes were not at all sensitive to cable motion or my touching of the electrode cables! The buffer amplifier on each active electrode appeared to be solving this problem as designed. Second, the envelope signal (derived from the raw EMG signal) from the MyoWare drifted unpredictably with the passive electrodes attached, but with the active electrodes, the envelope signal reliably returned to zero volts after each measured muscle contraction. This appeared to explain why we had previously had unpredictable issues with muscle recordings using passive electrodes. Third, with the active electrodes, the measured signal was still quite sensitive to any motion of the electrode cables that caused a shift in contact between the skin and the electrode patches. This mirrored Nalco's earlier observation that the weight of the cables on the patches would be an ongoing problem.

Nalco, as we shared in December, did not have access to a MyoWare 1.0 and was instead using MyoWare 2.0 hardware, preventing his use of the convenient MyoAES. Instead, Nalco modified the MyoWare 2.0 and its accessory boards to accommodate his testing with the active electrodes. He proceeded to compare the noise performance of the active and passive electrodes. Connected to his forearm with the same cables and electrode patches, he measured a slightly smaller noise floor with the active electrodes when in the idle state—not a large difference, but measurable. When the cables were mechanically disturbed, the passive electrodes yielded signals even larger in amplitude than the largest muscle signals measured by the same setup. The active electrodes showed no sign of this interference, perhaps because the wires he used to connect the electrodes were smaller and lighter than the heavy TRRS cables I had used in my setup.

Based on our collective observations, we can conclude that the active electrodes have substantially improved our ability to measure muscle signals as long as the electrical contact between the skin and the electrode patches is protected. We have several ideas for mitigating this vulnerability as well as improving the electrical system as a whole.

Software

As of our last software update, Mecknavorz was deep in the midst of troubleshooting the synchronization of data transfer between our ESP32 microcontroller and the host computer for the live grapher, a program that would display our muscle signals in real time. The ESP32, of course, was responsible for converting analog muscle signals from the MyoWare into digital data that could be transferred to the computer. Things became more complicated when we required a Python program to receive and plot that data in real time. Meck developed prototype functions in Python to handle data transfer, error correction, and plotting.

Since Pepper joined the Tail Project this past February, Meck and Pepper have been collaborating closely on our measurement software. Pepper has helped to test and debug the Python portion of our codebase. For instance, she developed a suite of test data representing the types of errors that we expected to encounter during real data transfer from the ESP32, and used these testdata to ensure that the error correction functions could correctly handle each type of problem. Pepper also confirmed that the error correction code could more than keep up with data transfer from the ESP32, with projected decoding rates of up to 45000 samples per second!

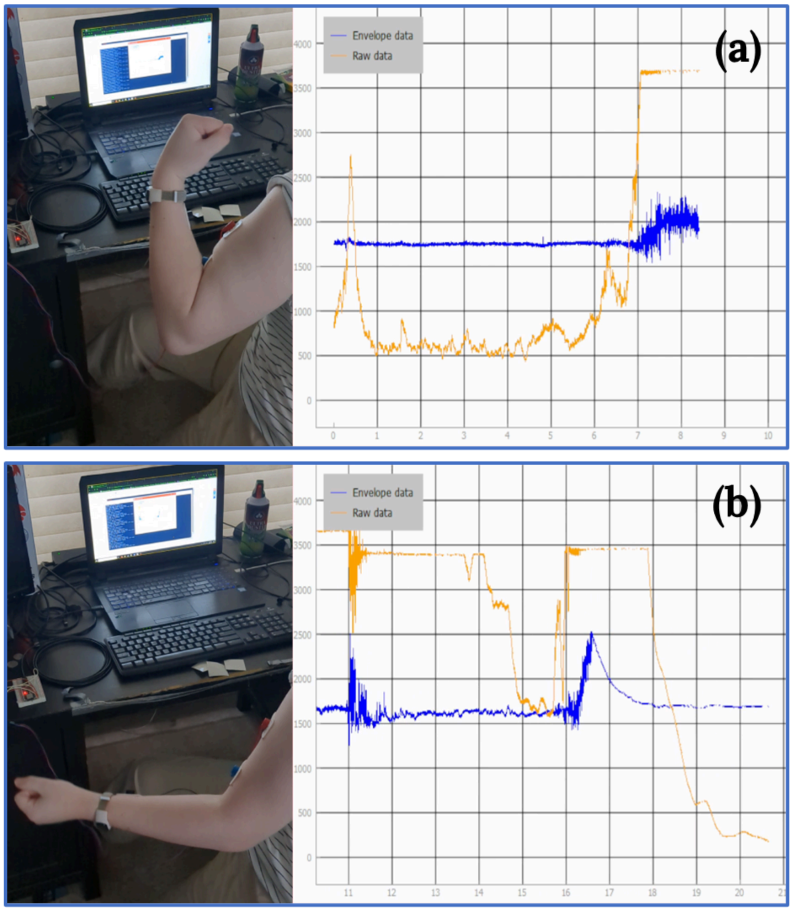

Fig. 2. Composite images of the Tail Project EMG live grapher receiving signals from a MyoWare equipped with passive electrodes. The horizontal axis on each plot is in units of seconds, with the most recent data on the right. (a) The envelope signal rises to saturation when the test subject contracts their biceps. (b) The envelope signal drops to zero after the subject relaxes their biceps.

The live grapher was successfully demonstrated after a few more key changes to the codebase. On the ESP32, after some experimentation with FreeRTOS, Meck improved the consistency and rate of sampling (to well over 1000 Hz!) by using hardware timers and interrupts to trigger each sample. On the Python code, Pepper found that matplotlib was too slow to enable live plotting and switched to using the pyqtgraph library. Pepper also implemented a system that grouped blocks of data for plotting (0.5 seconds at a time, for now). With these improvements, we were able to demonstrate the live grapher working with the MyoWare and passive electrodes (Figure 2).

This is another milestone for the project that completes our ability to record our muscles in action and to get live feedback on how the system responds to that muscle action. With some quality-of-life improvements and speed improvements, this software will be a valuable companion to our development efforts that we can extend with more functionality as needs arise.

Next steps

With the hardware and software of the measurement system functioning as designed, it's time to take some recordings of target muscles in the lower back. (Nalco has already started this process, in fact—more details to come.) These muscles are the primary candidates we hope to use for intuitive tail control, especially those that are analogues to extrinsic muscles of the tail in other mammals. At the same time, we intend to delve deeper into understanding what our measurement system is telling us with these recordings. Classifying and quantifying the muscle signals we record will be an important step towards linking muscle action to wearer intent and, ultimately, prosthetic motion.

We aim to upload some more comprehensive project documentation and technical details in September.

We thank FFF staff, volunteers, and the community for their support. The equipment used in this work was paid for by FFF donors.

More details about the tail project are at: https://freedomofform.org/research/enhanced-tail/

Volunteer Spotlight: Lathreas

By SvarOS | July 31, 2024

An interview with our Chief Technology Officer

Profile:
Specializing in Nanobiophysics, Lathreas is passionate about unraveling patterns within life's complexities. Conducting research that spans from theoretical models to practical laboratory investigations, their primary goal is to decipher the underlying “programming language” inherent to biological systems. With a record of diverse studies, Lathreas has explored cellular processes related to spindle orientation during division and delved into the intricacies of DNA repair protein functions, scrutinizing how specific amino acids affect DNA binding. Their recent research focuses on creating programmable patterns through diffusive interactions among synthetic DNA strands. All in all, they aim to continue research to pave the way to potential breakthroughs in managing cellular aging and developmental processes.

Lathreas also enjoys a variety of personal pursuits, including 3D digital modeling using Blender, electronics, programming, storytelling, and outdoor excursions, all of which complement their philosophical interests and lifelong dedication to scientific exploration inspired by a profound respect for nature. These leisure activities often intersect with professional endeavors, exemplified by their development of intricate mathematical models and simulations to depict complex biophysical interactions at a cellular level in three dimensions.

Driven by the aspiration to manifest their identity physically, in 2014, Lathreas embarked on a journey to enable precise morphological transformations through research, which informed the decision to delve deeper into nanobiology. Proactively venturing into 3D anatomical modeling, they initially conceptualized a feasible morphological target as a prototype. This early model has evolved with Zennith's skeletal and muscular research into the wolf skin and fur construct currently utilized in the FFF project. As part of the FFF team since 2020, Lathreas contributes expertise in anatomic modeling, conducts

comprehensive literature reviews, and remains committed to maintaining a sharp focus toward achieving transformative research objectives.

Interview:
SvarOS: So, what's your role within the organization for those unfamiliar with you?

Lathreas: My name is Lathreas, and I currently hold the role of CTO [Chief Technology Officer] in the organization. This means that my tasks are rather diverse. One of my tasks within the scientific leadership team is to ensure that our research is well-rounded and practically feasible. Beyond that, I have been supervising several other volunteers — who I must say have produced some excellent results — and large chunk of my tasks has been the modeling of various biophysical phenomena that aim to answer specific questions about the feasibility of our projects.

SvarOS: You helped create our research roadmap. Now that things have been mapped out, what are the next steps?

Lathreas: Good question! Now that the higher-level planning has been mostly pinned down, we can focus more on getting the lower-level projects on a sound footing. This will be a mixture of more concrete physical and geometric modeling at first, such as the design of implants or surgical procedures, in particular for snouts. We also have a list of drylab and wetlab research questions that need answering in relation to integument (fur/feathers/scales), and we are currently setting up a pipeline to answer those. These concrete questions are balanced by feasibility studies of key areas that still need to be covered, such as to answer whether it is reasonable to think that irises can be increased in size. Due to the time budget being limited, getting the balance just right is quite important, so that will be something that we pay special attention to.

SvarOS: In your bio, you describe yourself as a “nanobiophysicist.” Could you explain to the reader what that means?

Lathreas: Yes, of course! My official educational background is that of Nanobiology, a rather new and interdisciplinary field at the intersection of mathematics, physics, and biology at the nanoscale. Officially, that makes me a nanobiologist, but given the deep focus on the physical aspects of biology, I find “nanobiophysicist” to be more descriptive. And this physics is quite important! By understanding exactly how the laws of physics apply to biology at the nanoscale, it becomes possible to see life no longer as squishy things that you can treat with chemicals, but rather as a complex machine where each part has a function. Understanding how a body works requires thinking about life at multiple scales, from the smallest to the largest. Given that, on a smaller scale, life turns out to be quite engineerable!

> *“Understanding how a body works requires thinking about life at multiple scales, from the smallest to the largest.”*

SvarOS: What application and promise do you think this field has?

Lathreas: Science already has a reasonably good view of the fundamental aspects of physics at the nanoscale. We also have a good view of what biology does at the macro level. However, explaining how biology does all those things purely with the tools of fundamental physics is still unclear. It is now emerging as one of the next steps in understanding biology. This is exciting, because it's one of the pivotal points that could make biology as engineerable as stuff that we know well, like robotics. Though fascinatingly, due to life’s squishy and somewhat chaotic nature at the nanoscale, oftentimes whole new areas of physical modeling need to be explored to make us able to understand what is going on.

SvarOS: So, nanoscale biology is about understanding the cell's inner workings and how parts talk to one another so that we can mimic that sort of thing in the future. Is that correct?

Lathreas: Broadly, yes! However, I would argue that this is not just an endeavor to mimic biology in the future. Indeed, it's an important aim, and I know that research is already underway to create the first fully synthetic biological cell. Still, a much more immediate application is in engineering the cells that life has already provided for us. Not in small part, this includes fixing kinds of diseases, which can have significant nanobiological aspects. Certain cancerous cells, for example, have been shown to escape easily when the extracellular matrix, a rope network of many long molecules outside a cell, has different physical properties, such as softness or hardness. Understanding what influences those physical properties is part of biophysics research, although none of which I am currently involved in, and it shows a clear relevance to diseases of today. Another example is DNA repair, which requires a deep understanding of the proteins' function, which I do have some lab experience in.

SvarOS: This seems like a unique discipline. What drew you to this?

Lathreas: What I like about Nanobiology is that it focuses deeply on the inner workings of cells, tissues, and organisms and aims to explain in concrete detail the physical behavior of a system to get it to the level that we understand rocket science. Life, however, is far more difficult, because we don't yet get to design neatly separated parts. Evolution wrote a mess of code, if you want to put it that way. But that also excites me because, with every step of research, we understand more and more about how beautifully machine-like life is, even if it functions fundamentally differently from any of the machines we know in our daily lives.

SvarOS: Are there any examples you've done that could tell the reader how these disparate fields can come together?

Lathreas: One example is some of my previous work involving the modeling of microtubule organization in cells. Microtubules are nanoscopic 'ropes' that have various functions inside a cell. In the context of cell division, they physically push and pull on the cell membrane to orient the plane of cell division. This is a highly nanophysical process that has incredible importance to the growth program of an organism, and understanding how that works helps us understand how one day we may be able to program cells to divide horizontally, but not vertically. Another example is in the analysis of genetic circuits, in which it is incredibly important to understand the dynamics of the signaling systems. Like electrical circuits: phenomena such as 'crosstalk' and resonant feedback (like when holding a microphone close to its speaker leads to a shrieking noise) can occur, which causes systems to go haywire in many interesting ways that are unclear if not for modeling efforts.

SvarOS: How does this apply to the Foundation? What can this programmability for cells do to help achieve Freedom of Form?

Lathreas: Perhaps more relevantly for the FFF, nanobiophysics is incredibly important specifically for developmental biology, which is the field of study that examines how organisms grow. Beyond genetic programs that do "something" to grow a whole organ, cells have to physically move from place to place, adapt to their physical environment, communicate chemically with surrounding cells, and pattern their tissues. Patterning is particularly important, because it is one of the main methods by which growing or changing bodies tell their tissues what shape to take. It does so by laying out *morphogen gradients*, which are subsequently read out by the cells to initiate growth programs. All of these aspects are highly physical and mathematical, and understanding them can help us understand how to alter them.

SvarOS: Could you give an example?

Lathreas: My favorite type of patterning is Turing patterning, which is a type of patterning that allows regular spots and stripes to emerge almost out of nothing. Still, we understand how they work, because of mathematical modeling pioneered by Alan Turing. Many decades later, scientists have revealed that slightly more complex cases of those biophysical phenomena drive the formation of scales on snakes and fish, can determine the number of hair follicles on a patch of skin, and so forth. And fascinatingly, the mathematics tells us that if we know the system, we can engineer it to produce different patterns, offering hope that we could potentially, one day, alter the patterning systems that exist in our bodies (that create fingerprint patterns, for example) and make them form scale-like patterns instead. Those patterns can subsequently be read out by the cells to grow the actual scales. The advantage of Turing-like patterning is that these patterns form autonomously, as opposed to having to manually insert the starting points of each scale into a patient. That said, such autonomous patterning would be a rather futuristic option, as there are still many open research questions. It is important to keep in mind that earlier versions of treatments likely have to resort to less futuristic mechanisms with less technical risk, even if that means that each treatment is more labor-intensive.

> *“...the mathematics tells us that if we know the system, we can engineer it to produce different patterns, offering hope that we could potentially, one day, alter the patterning systems that exist in our bodies...”*

SvarOS: Speaking of modeling. You mentioned that you were working on one for cell division. What cell division software are you creating?

Lathreas: So, the software that I have been working on in my free time has been one that aims to produce an easy way to simulate the behavior of various genetic programs in the development of tissues. This means simulating the inner state of each cell in a way that mimics real life quite well, but also simulating the physical interactions that cells have with one another. Sadly, however, there's still too much unknown about cellular processes to make any such software capable of simulating anything more complex than an exceptionally simple organism. But even so, each successful simulation is a step in the right direction. My goal is to get something that can give faster results to users and massively increase the framerate and performance of these models.

SvarOS: Why are framerate and performance so important?

Lathreas: Many programs are available that can simulate cells and tissues in some fashion, though all are highly simplified and answer a single research question. Mine will be no different, but one of the major caveats I have noticed with many other research software was that the algorithm that adds new cells to the list was not easily optimized on consumer-grade computer hardware. Given this, the solution up until this point has been to place them on some of the most powerful supercomputers and hope for the best. Timesharing on such things is impractical to most researchers and usually allows someone to view the output only after the full simulation. I decided to try implementing such a simulation tool on consumer-grade graphics cards instead. Despite the limitations of a “gaming” computer, I managed to get it to work quite well: a real-time framerate of up to a million cells while displaying it in real-time; importantly, with cell division included. This could allow for much faster feedback between trying new genetic circuit models and seeing their behavior.

SvarOS: You don't just work on the micro scale; you've also done a little macro modeling. Describe the models that you use to help model other species. What are their purposes?

Lathreas: One of the big challenges we face in our quest to give people the body they want is that we want to create something for which we have no good anatomical reference. Such a reference is essential to be able to design treatments. After all, we can't just go hacking and slicing into people and hope for the best because where would we even begin? In all biology, the form determines function, and as such, we do not have a clean canvas upon which we can try any shape. Any change we make to the human body can and will change the function somehow, and we have to assess whether or not that change has the desired outcome. As such, modeling is a great way to answer many questions without risk. It gives us an example of what we can expect.

> *"In all biology, the form determines function ... Any change we make to the human body can and will change the function somehow."*

SvarOS: Haven't we been doing so through drawings? What do the models add, and how do they point and direct research?

Lathreas: We are used to seeing beautiful, stylized drawing-based artworks of anthropomorphic creatures, but will they even look right when we do it in real life? By making a photorealistic version based on careful sculpting and modeling, we can assess whether it is even a worthwhile endeavor in the first place. Secondly, by having such a model, we can easily see what changes are necessary to the underlying bone structure, assess the risk to the patient, and adjust our expectations if necessary. For example, is it necessary to move eyeballs further apart? Is it feasible? What happens if we don't? Does the result still look decent, or does it look so bad that nobody would want this anymore?

SvarOS: So, it focuses on the practical aspects of the research and how such constructions could be done?

Lathreas: Yep, indeed! Modeling lets us know what combination of treatments will be necessary to create something palatable and helps keep us honest. We will know the effects if we cannot do one of the treatments. And it gives people a better view of what they can expect from a combination of treatments and how much impact this may have. This way, we can balance risk with aesthetics and find a good middle ground that people would still love to get. Of course, modeling does not answer all questions, but it certainly does answer many essential ones while remaining relatively cheap.

SvarOS: Do you use special tools or software? Is it something you made?

Lathreas: For modeling, I primarily use Blender. It's an amazing software suite that keeps improving and improving; importantly, it's free and open-source! Even so, its extensibility and ability to make photorealistic renders are amazing, and especially photorealism is important to get a more honest picture of what we can expect. After all, stylized renders can obscure uncanniness in ways that photorealism doesn't. It's the closest we can get to "What you see is what you get".

SvarOS: Are there plans to update them for other species?

Lathreas: I do indeed intend to model many more species beyond wolves. This depends on whether we can safely model the iris size into something that can be simulated practically. Before committing to it, I want to do a few feasibility studies because, unlike wolves, many other popular creatures, such as big cats, foxes, and various types of dragons, benefit greatly from enlarged irises. Once we've found a way to do that, having that 'tool' in my 'toolbox' will help me to create an aesthetically pleasing and yet practical result. Additionally, it would certainly improve the wolf we already have.

SvarOS: You have a ton of hobbies, including hiking, biking, tinkering, doing your job, and the FFF. What do you enjoy the most?

Lathreas: Ooh, good question. I must admit that I find it difficult to answer which one I like best, as it depends on the mood. Whenever my energy level is lower, I try to go hiking or bicycling, but very often, I will have creative energy that I need to put into a project, and then I start tinkering. I think the biggest asset to my time management is the fact that I can combine things. Luckily, I live quite close to my university with a 30-minute commute by bike, meaning I will have a nice amount of exercise. However, that doesn't mean that the occasional 7 AM commute in heavy rain and going against the wind is fun, haha. But it helps to see the positive rather than the negative side. It could just as well be a free shower! When I feel more energized, I try to spend some time in the library or at home putting some stuff together. Luckily, because my work during the daytime, as well as for the FFF, primarily involves research, much of my time is spent reading scientific texts. And that means I can take books or a tablet into the local woods, even if those woods are small, and combine hiking with reading!

SvarOS: How do you fit it all in?

Lathreas: I'll admit I make it sound like I do a lot daily, but that's not always true. The types of rhythms that work for someone else may not work for me, and vice versa. At least for me, I get a lot more productive if I take 'sprints' of about two weeks with high productivity and then follow that with one week of relaxation where I focus on the essentials. Sometimes, that means spending as much of my spare time as possible in the woods doing nothing so the creative juices start flowing again. When I do it right, I will intrinsically feel motivated to do a lot of stuff again without it costing me much energy, and I will intrinsically feel when that moment arrives. Sadly, the world is not always built to accommodate that rhythm, which is split into fixed five-day workweeks and two-day weekends, and that can be difficult to work around when my rhythm happens to misalign with that rhythm. But the more I combine things, the better things tend to go. Spending the 'relaxation' week on a semi-low burner, so to speak, still gets things done within the commonly accepted frame while still giving a decent boost to productivity in the coming weeks.

SvarOS: What time management secrets can you give?

Lathreas: I think my most important tip concerning time management would be to optimize your energy levels, not for your time. Sleep is important, as is healthy eating. Additionally, what helps me is to box things off. Whenever I focus on one thing, everything that could remind me of the other things on my plate is removed. Including on my computer. I use strict context separation to ensure I can truly unload unneeded stressors from my brain whenever I focus on a different task. I find it better not to try to multitask. That's different from combining things when possible (e.g., bicycling in nature as part of a commute) because multitasking does not reduce the workload. It requires constant loading and unloading of information in the brain, and I find it best to work on one task deeply rather than two tasks shallowly if that makes sense.